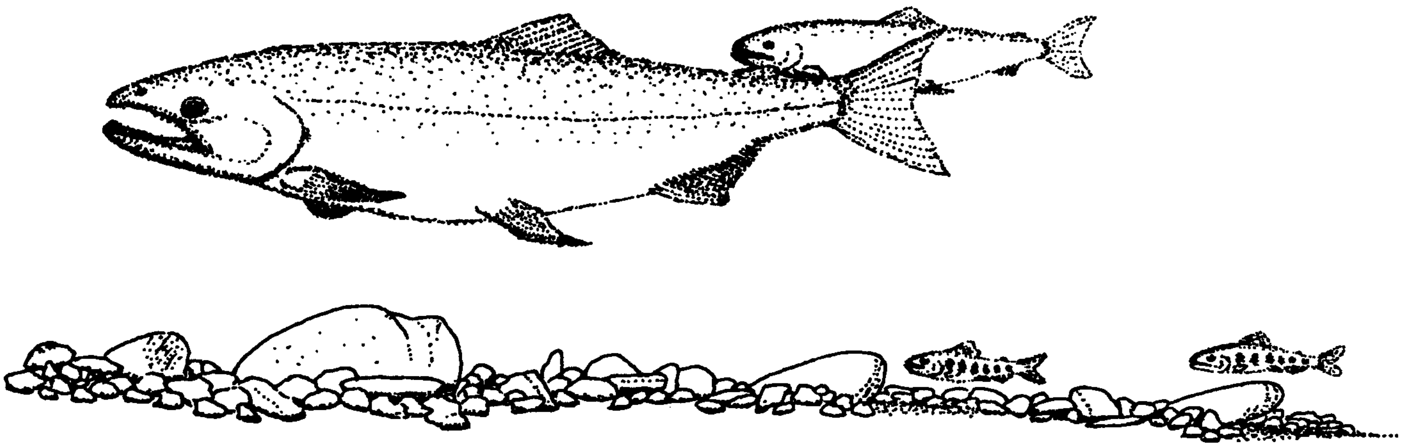
U.S. DEPARTMENT OF THE INTERIOR

FISH AND WILDLIFE SERVICE

AN EVALUATION OF INTRODUCED WOODY DEBRIS BUNDLES TO INCREASE SUMMER DENSITIES OF JUVENILE COHO SALMON IN THE MAINSTEM CLEARWATER RIVER, WASHINGTON



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An Evaluation of Introduced Woody Debris Bundles to Increase Summer Densities of Juvenile Coho Salmon in the Mainstem Clearwater River, Washington

by

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ABSTRACT

We studied the use of woody debris introductions as a habitat restoration technique for increasing juvenile coho salmon (*Oncorhynchus kisutch*) summer rearing densities in the mainstem Clearwater River (mean discharge = 39 m^3/s) and immigration into overwintering habitat. Non-permanent evergreen tree bundles were used as introduced woody debris structures to test the hypothesis that summer rearing densities of coho salmon in the mainstem could be increased using habitat restoration measures. Juvenile coho salmon summer rearing densities were higher in reaches enhanced by introduced woody debris than in control reaches and were positively related to woody debris density (no. pieces of wood/km). However, immigration of juvenile coho salmon into wall-base channels, a significant overwintering habitat in this system, was not higher in enhanced than control reaches.

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INTRODUCTION

During summer 1990, the Washington Cooperative Fish and Wildlife Research Unit, U.S. Fish and Wildlife Service, and Washington Department of Natural Resources began evaluating the potential to increase juvenile coho salmon (*Oncorhynchus kisutch*) summer rearing habitat in the mainstem Clearwater River by introducing woody debris bundles. Woody debris is an important component of salmonid habitat, serving two primary functions, pool formation and providing protective cover (Bisson et al. 1987). Woody debris provides two forms of protection: cover from predators (Everest and Chapman 1972; Grant and Noakes 1987) and reduction of current velocities (McMahon and Hartman 1989; Shirvell 1990; Fausch 1993). As an example, young-of-the-year brook trout have a shorter reactive distance to predators in areas with concentrated cover, increasing their foraging opportunities (Grant and Noakes 1987). Woody debris also prevents the displacement of juvenile salmonids from rearing areas (McMahon and Hartman 1989). Areas containing woody debris are often the preferred habitat of juvenile coho salmon during the summer (Lister and Genoe 1970; Bisson et al. 1982) and winter (Bustard and Narver 1975a, 1975b). Numbers of salmonids are often positively related to debris density (House and Boehne 1986; McMahon and Holtby 1992) and salmonid biomass decreases after the removal of woody debris (Bryant 1982; Dolloff 1986; Elliott 1986).

Hall and Baker (1982) recommend that the rehabilitation of salmonid rearing areas be emphasized and Sedell and Luchessa (1982) encourage the restoration of habitat complexity to mainstem channels of 4^{th}- to 7^{th}-order streams. Summer carrying capacity of salmon and trout streams has been increased with the addition of woody debris (Ward and Slaney 1981; Anderson 1982; House and Boehne 1985, 1986; Nickelson et al. 1992b). However, most examples of habitat enhancement have occurred in relatively small streams (1^{st}-3^{rd} order). Common techniques of enhancement involve the addition of stable debris to provide resting areas, overhead cover, and new pools (Bisson et al. 1987). Sedell et al. (1985) predicted that salmon production in debris-impoverished streams could be increased by increasing the debris load. Hall and Baker (1982) also suggested that these measures would enhance existing wild stocks and maintain their genetic variability.

If mainstem restoration through woody debris introductions is successful, the potential limitation to coho salmon production in the Clearwater Basin (Cederholm and Reid 1987) may be eliminated and immigration of coho salmon into wall-base channel ponds during the fall may increase, thereby increasing production in this system. The specific objectives of this study were to determine whether juvenile coho salmon summer rearing densities in the mainstem Clearwater River could be increased by introducing woody debris and whether this would increase juvenile coho salmon immigrations into wall-base channel ponds during the fall.

Study Area

This study was conducted on the mainstem Clearwater River and six of its riverine ponds (Figure 1). The Clearwater River originates from the west slope of the Olympic Mountains, flows west to southwest for 58 km to its confluence with the Queets River (Winter 1992). The river's drainage area of approximately 350 km^2 (Cederholm and Scarlett 1982) receives over 350 cm of rain annually (Cederholm and Scarlett 1991). The river is fed primarily by surface runoff and ground water (Winter 1992). Median discharge near the town of Clearwater for the years 1932 and 1938-1949 ranged from about 3.7 m^3/s to 9.3 m^3/s from June to September; a peak flood of 1,059 m^3/s was recorded 3 November 1955 (Amerman and Orsborn 1987).

The study area extends from Bull Creek (Rkm 30) downstream to a creek described as 0031 Creek (rkm 10). The river gradient in this reach is low to moderate and the river is composed primarily of pools with relatively short riffles. Juvenile coho salmon immigration was monitored at six riverine ponds (Figure 1, Table 1). Coppermine Bottom, Pond 2, Paradise and Swamp Creek Beaded Channel have been described previously (Peterson 1982a; Cederholm et al 1988; Cederholm and Scarlett 1991). Paradise Pond and Swamp Creek Beaded Channel were the subjects of earlier enhancement projects (Cederholm et al. 1988; Cederholm and Scarlett 1982) and are located on opposite sides of the river at approximately rkm 15.3. Morrison Pond is a relatively small pond bordered by an extensive sedge swamp, whereas Airport Pond is actually two adjacent ponds with a single outlet. The ponds are typical wall-base channel ponds in differing stages of succession (Peterson and Reid 1984).

Table 1. Summary of the physical features of the six wall-base channel ponds where juvenile coho salmon were sampled. (Source: Peterson 1982a; Cederholm et al. 1988; Cederholm and Scarlett 1991; Dave King, Washington Department of Fish and Wildlife, unpublished data).

Pond	Surface area (ha)	Outlet length (m)	River kilometer
Coppermine Bottom	0.9	350	27.4
Pond 2	1.3	350	20.0
Paradise	0.5	350	15.3
Swamp Creek	0.3	220	15.3
Airport	1.4/2.1	150	7.2
Morrison	1.0	150	4.8

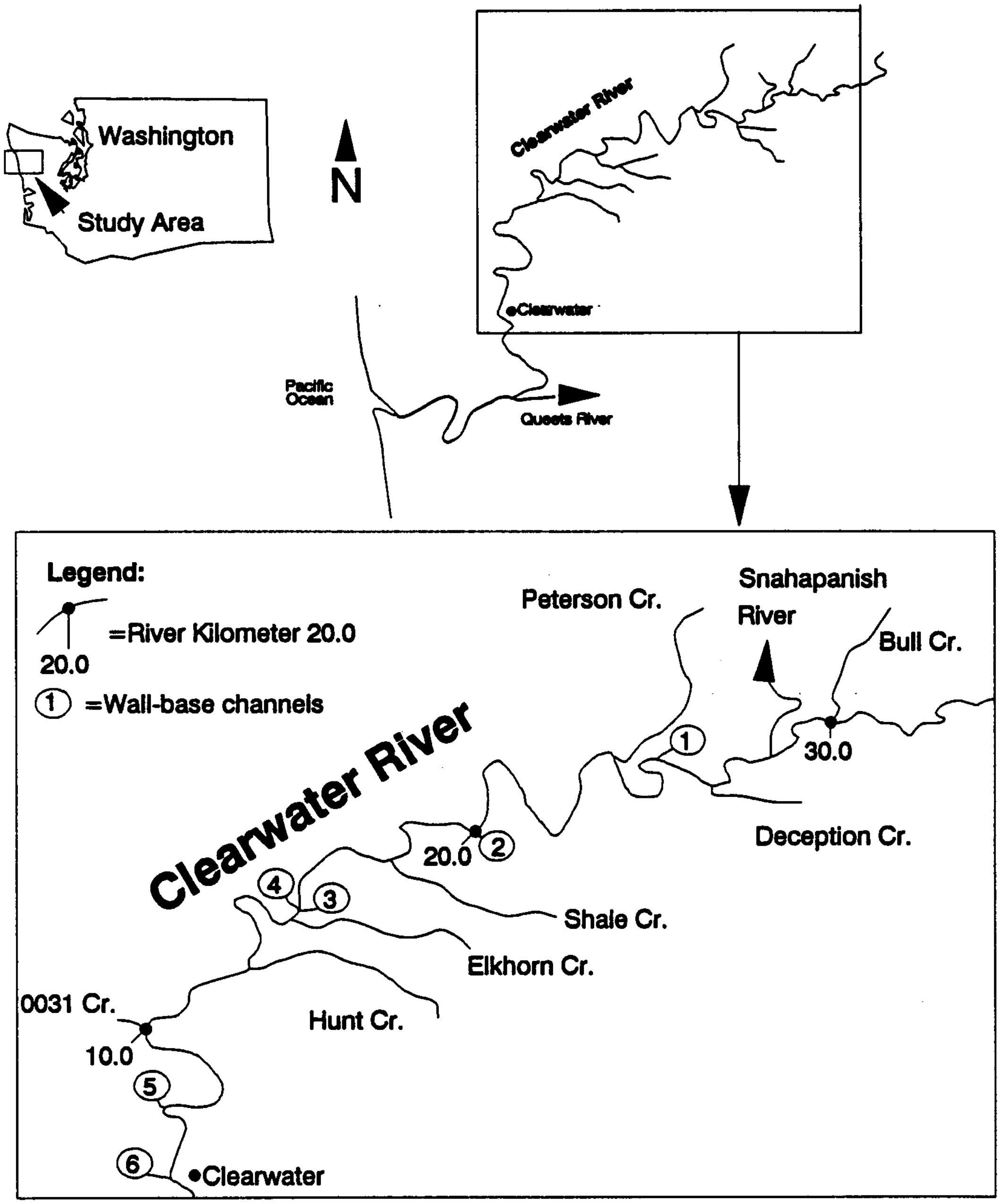

Figure 1. **Study area of the mainstem Clearwater River. Study reaches described in the materials and methods section were Bull Cr. to Deception Cr. (2.4 km), Deception Cr. to Peterson Cr. (4.0 km), Peterson Cr. to Pond 2 (4.0 km), Pond 2 to Shale Cr. (2.1 km), Shale Cr. to Elkhorn Cr. (2.4 km), Elkhorn Cr. to Hunt Cr. (2.4 km), and Hunt Cr. to 0031 Cr. (2.4 km). Wall-base channels monitored for coho salmon immigrants were (1) Coppermine Bottom Pond, (2) Pond 2, (3) Paradise Pond, (4) Swamp Creek Beaded Channel, (5) Airport Pond, and (6) Morrison Pond.**

MATERIALS AND METHODS

Comparison of Enhanced and Unenhanced Reaches

A 2-year study design was used to evaluate the effect of habitat enhancement on juvenile coho salmon summer rearing densities. Following preliminary observations during 1990, seven adjacent study reaches were established in the mainstem Clearwater River (Table 2). One reach, approximately 2.1 km in length, was unaltered during both years (1992 and 1993) to serve as a year-to-year control. Of the six remaining reaches, four were approximately 2.4 km long and two were approximately 4.0 km long (Table 2). During the first year (1992), the habitat in three randomly selected reaches (two 2.4-km and one 4.0-km reaches) was enhanced by introducing 10-20 woody debris bundles to each (enhanced reaches). The three remaining reaches were unaltered (control reaches) (Table 2). Treatments were reversed during 1993. The three control reaches from 1992 were enhanced during 1993 by introducing 10-20 woody debris bundles. The three enhanced reaches from 1992 were returned to their natural state during early spring 1993 by removing introduced woody debris bundles remaining after the winter so they could serve as control reaches (Table 2).

Woody debris bundles were installed by a 10-person crew during early May at predetermined stations within each reach. Two or three sitka spruce (*Picea sitchensis*) or western hemlock (*Tsuga heterophylla*) trees, averaging 10-20 cm diameter at the base, were removed from the adjacent riparian zone and carried to the river's edge, where they were laid parallel and joined at their butt ends with rope or a large metal spike. The bundle of trees was then rolled into the river and then floated to the desired position, where it was lashed in a submerged position to an existing tree or rock.

Juvenile coho salmon abundances were estimated for each study reach, during early (June/July) and late summer (August/September). Abundance estimates were made in each reach by summing snorkel-count estimates of coho salmon abundance at three types of stations (natural, introduced, or no debris) within each reach (two station types in control reaches without introduced debris). Stations composed of only naturally occurring woody debris were classified as natural and were present in both enhanced and control reaches. Stations where woody debris was introduced were classified as introduced and were only present in enhanced reaches. Control stations were areas that were similar to natural and introduced debris stations, except the area lacked woody debris. Control stations were present in both enhanced and control reaches. Two snorkelers entered the river upstream of the survey station and proceeded downstream, counting juvenile coho salmon as they passed the station. Once downstream of the station, the snorkelers proceeded upstream, again counting juvenile coho salmon as they passed the station. The snorkelers then discussed their individual estimates and came to a consensus, which became the abundance estimate for that station.

Table 2. Treatments and lengths of study reaches during 1991-1993. Number in parenthesis represents the number of introduced woody debris stations in enhanced reaches.

Reach name[1]	Treatment 1991	1992	1993	Approx. length (km)
Bull	Enhanced(8)	Control	Enhanced(7)	2.4
Deception	Control	Enhanced(9)	Control	4.0
Peterson	Enhanced(20)	Control	Enhanced(14)	4.0
Gross	Control[2]	Control[2]	Control[2]	2.1
Shale	Control	Enhanced(10)	Control	2.4
Elkhorn	Enhanced(10)	Control	Enhanced(7)	2.4
Hunt	Control	Enhanced(12)	Control	2.4

[1]Reach names were selected based on tributary (or bridge) at the upstream end of the reach (i.e., The reach running from Bull Creek to Deception Creek = Bull Reach, Figure 1)
[2]Year-to-year control

The sum of the abundance estimates at all the stations surveyed in each reach was considered a minimum estimate for that reach. Estimates were considered minimum coho salmon abundance in the reach because stations rather than the entire reach were surveyed and snorkel estimates generally underestimate true abundances (Slaney and Martin 1987). Although no quantitative estimate is available, the author believes that greater than 90% of juvenile coho salmon within a reach were seen using the above methodology and snorkel estimates represented approximately 67% of actual coho salmon abundance at stations (Appendix B). Minimum juvenile coho salmon densities were calculated by dividing the minimum abundance estimates for the reach by the reach length (coho salmon/km). A sign rank test was used to compare coho salmon rearing densities in enhanced and control reaches during June 1991-1992, June 1992-1993, and August 1992-1993.

The influence of woody debris on estimated coho salmon densities in each study reach was examined using linear regression with estimated coho salmon densities as the dependent variable and the total number of natural and introduced woody debris accumulations present in the reach as the independent variable. Separate analyses were completed for the early summer and late summer survey data.

The study was originally planned for 1991 and 1992, following preliminary observations collected during 1990. However, an unusual storm in mid August 1991 brought 15 cm of rain during a 4-day period. This storm occurred after the early summer (1991) survey but before the late summer survey. Many of the introduced woody debris bundles were removed by the storm, thereby eliminating the treatment. For this reason, late summer survey data from 1991 does not appear in the results. The treatments for 1991 were replicated in 1993 in order to complete the 2-year study design.

Movement

A cursory examination of coho salmon movement was undertaken during the summers of 1991 (flood influenced) and 1992. Movement was examined by differentially marking coho salmon rearing at three (1991) and four (1992) mainstem debris accumulations. Coho salmon at selected stations were sampled using beach and purse seines during August 1991 and June 1992 and given a freeze brand (Bryant and Walkotten 1980) unique to that station. Movement of these marked fish was monitored by sampling coho salmon rearing at these and other stations throughout the summer and examining the fish for brands.

No direct examination of movement occurred during 1993. However, data from a microhabitat use evaluation (Peters 1996) could be used to assess movement. This data differed from that collected during 1991 and 1992 in that 10 coho salmon were marked at 18 woody debris accumulations and 14 at one additional debris accumulation. The fish were marked between 26 July and 2 August and recaptured between 13 September and 24 September.

Effect of Enhancement on Wall-base Channel Immigration

The effect of habitat enhancement on the number of juvenile coho salmon moving into wall-base channel ponds during fall and winter was evaluated. Following the late summer surveys in 1990 and 1992-1993, coho salmon were captured and marked at a number of natural and introduced debris stations within each reach. Because of the large number of stations, long stretch of river, and time constraints, attempts to capture juvenile coho salmon for marking were made only at stations with relatively large estimated populations (50 or more). Juvenile coho salmon were captured by beach or purse seining, anesthetized with tricaine methanesulfonate (MS-222), measured to fork length (mm), and weighed (g). Coho salmon were then marked using freeze branding (Bryant and Walkotten 1980) in 1990 and 1992, and by injecting acrylic paint into the caudal fin (Lotrich and Meredith 1974; Thresher and Gronell 1978) in 1993. After recovering from the anesthetic, fish were released into the debris station from which they had been captured. In 1992 and 1993 attempts were made to mark equal numbers of coho salmon from enhanced and control reaches, as well as from stations with natural and introduced woody debris to allow comparisons of the contribution of coho salmon rearing in these areas during the summer to immigration into wall base channel ponds during the fall. To accomplish this, a majority of coho salmon marked from enhanced reaches were from stations with introduced woody debris stations, although some coho salmon from stations with natural woody debris were also marked.

Coho salmon were captured and checked for marks as they migrated into wall-base channel ponds. Six wall-base channel ponds were monitored in 1992 and 1993 (Figure 1) while only four (Coppermine Bottom, Pond 2, Paradise, and Swamp Creek) were monitored during 1990 (Figure 1).

Coho salmon were captured as they migrated into these ponds from the first fall freshet through the end of December using upstream weirs and wood framed live-box traps. Fish were removed from traps, anesthetized, and checked for marks. A random sample of up to 25 coho salmon (marked and unmarked) were weighed (g) and measured to fork length (mm) each time the trap was checked. After recovery, the fish were released upstream of the trap.

A t-test, using arc sine transformed data (Zar 1984), was used to compare the recovery rates (percent marked fish recovered) at: 1) enhanced and control reaches of the mainstem, 2) introduced and natural debris stations, and 3) debris stations located in pools and glides. These analyses were completed with data from all three years separately and combined.

The number of coho salmon moving into wall base channel ponds from summer rearing areas located in control and enhanced reaches was estimated using the recovery rate and the estimated population size in each reach type. Estimated coho salmon abundance in control and enhanced reaches was multiplied by the percent of marked fish from each reach type recovered migrating into wall-base channel ponds to calculate the estimated number of coho salmon from each reach migrating into this habitat.

Coho Salmon Size Comparison

A number of comparisons of coho salmon fork lengths were completed using either a Student's t-test or a one-way ANOVA and Tukey multiple comparisons. A t-test was used to compare the fork length of juvenile coho salmon captured from enhanced and control reaches and those from introduced and natural debris stations during August (marking survey). ANOVA and Tukeys multiple comparisons were used to compare coho salmon lengths: (1) those captured from debris located in different riverine habitat (pools, riffles, and glides); and (2) those migrating into wall-base channels during the fall. A Student's t-test was used to compare the fork length of juvenile coho salmon captured from enhanced and control reaches and those from introduced and natural debris stations during August (marking survey).

RESULTS

Comparison of Enhanced and Unenhanced Reaches

Although coho salmon densities in mainstem study reaches varied between reaches and years, woody debris introductions appear to be an effective tool for increasing coho salmon late summer rearing densities in the mainstem Clearwater River. Coho salmon densities (fish/km) were generally higher in enhanced reaches than control reaches (Figures 2-4) and were positively related to woody debris densities (Figure 5). Coho salmon rearing densities were significantly higher in enhanced and control reaches during June 1991-1992 (Figure 2) and August 1992-1993 (Figure 4), but not during June 1992-1993 (Figure 3). Coho salmon densities were significantly and positively influence by increasing woody debris densities (introduced and natural woody debris accumulations/km) (Figure 5).

Movement

Limited movement of summer rearing coho salmon occurred between marking and recapture (Figures 6-8). Most marked fish were recaptured at the station where they were marked. However, there was a fair amount of movement between stations located within 100 m of each other. Most movement was in the downstream direction with some fish moving up to 9 km downstream. However, one fish moved approximately 1 km upstream from the station where it had been marked.

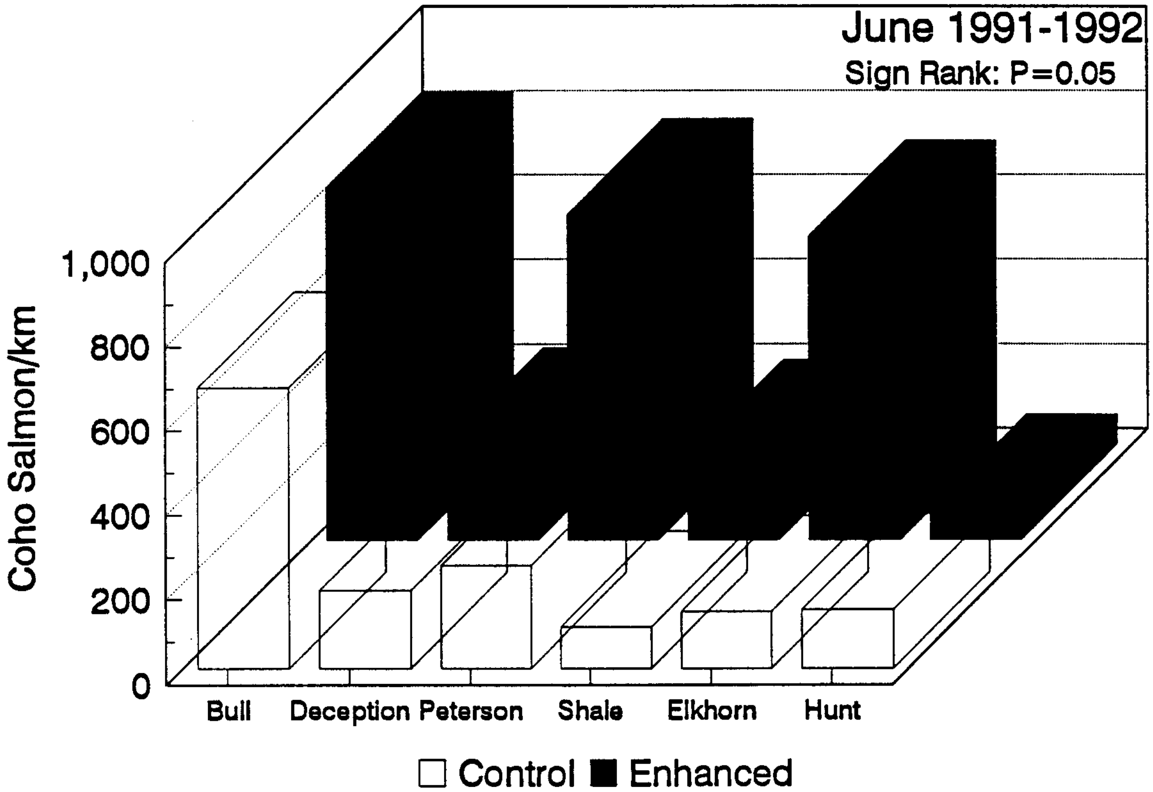

Figure 2. **Estimated coho salmon densities (coho/km) in the six study reaches when they were enhanced and when they were controls during June 1991-1992. Result of the sign rank test used to compare rearing densities in enhanced and control reaches is included.**

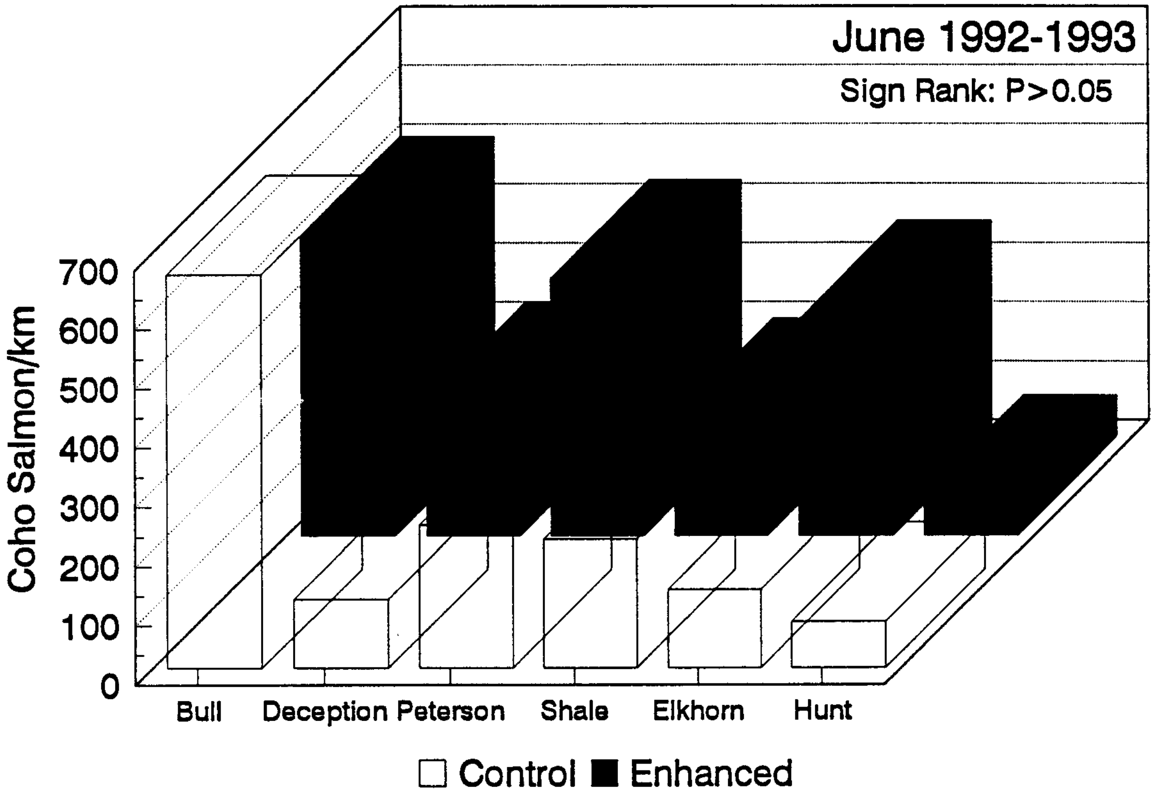

Figure 3. Estimated coho salmon densities (coho/km) in the six study reaches when they were enhanced and when they were controls during June 1992-1993. Result of the sign rank test used to compare rearing densities in enhanced and control reaches is included.

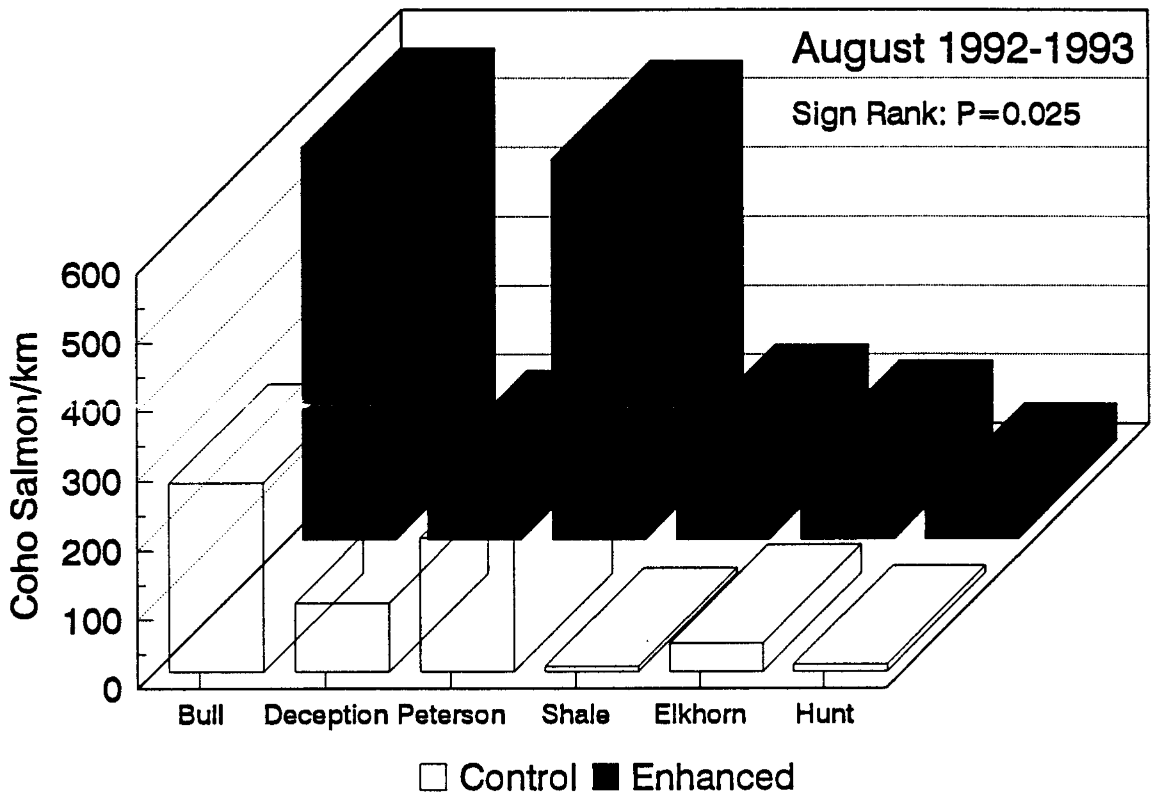

Figure 4. **Estimated coho salmon densities (coho/km) in the six study reaches when they were enhanced and when they were controls during August 1992-1993. Result of the sign rank test used to compare rearing densities in enhanced and control reaches is included.**

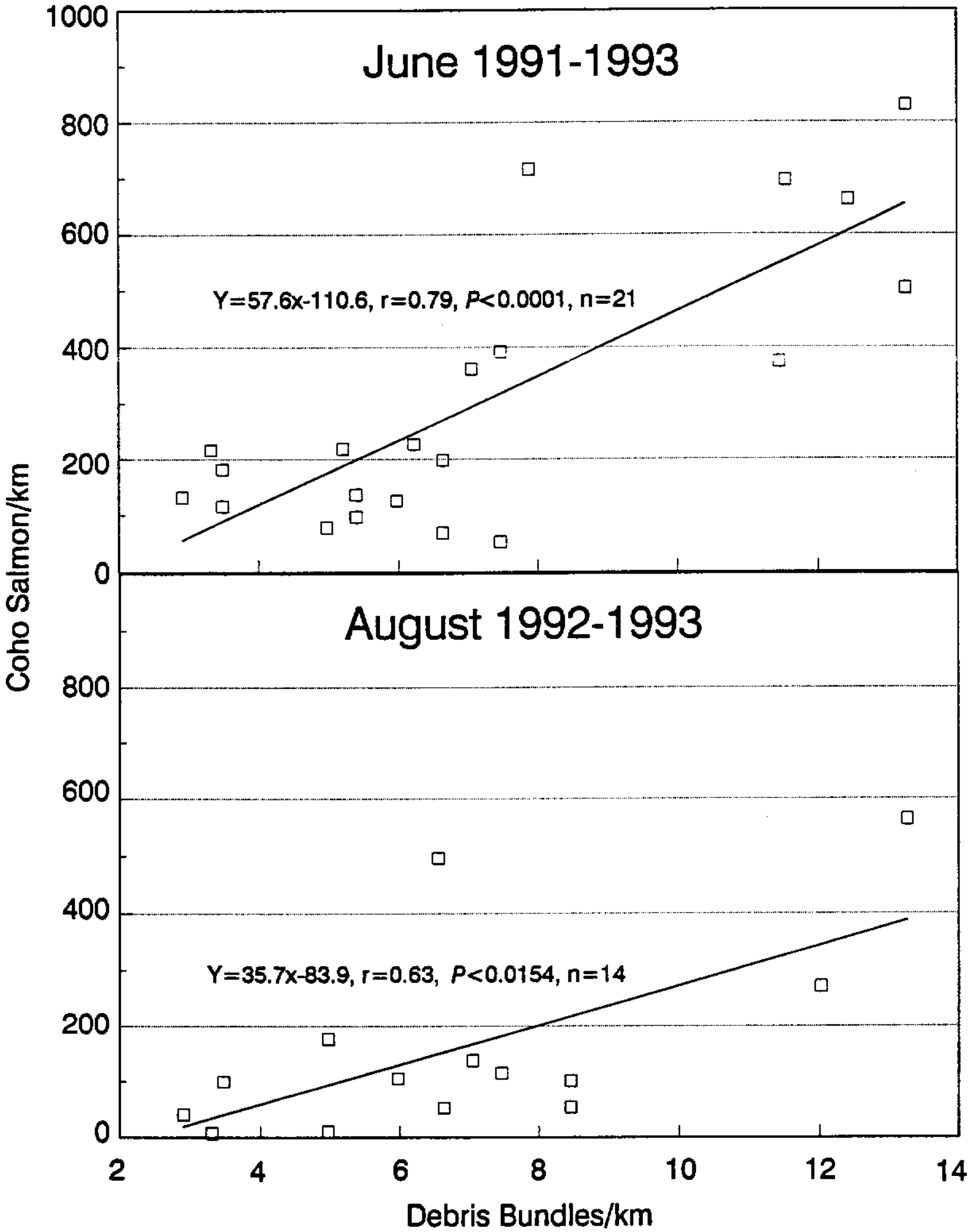

Figure 5. **Relationship between estimated coho salmon population densities per kilometer of river and the number of debris stations per kilometer of river (June/July 1991-1993 and August 1992-1993).**

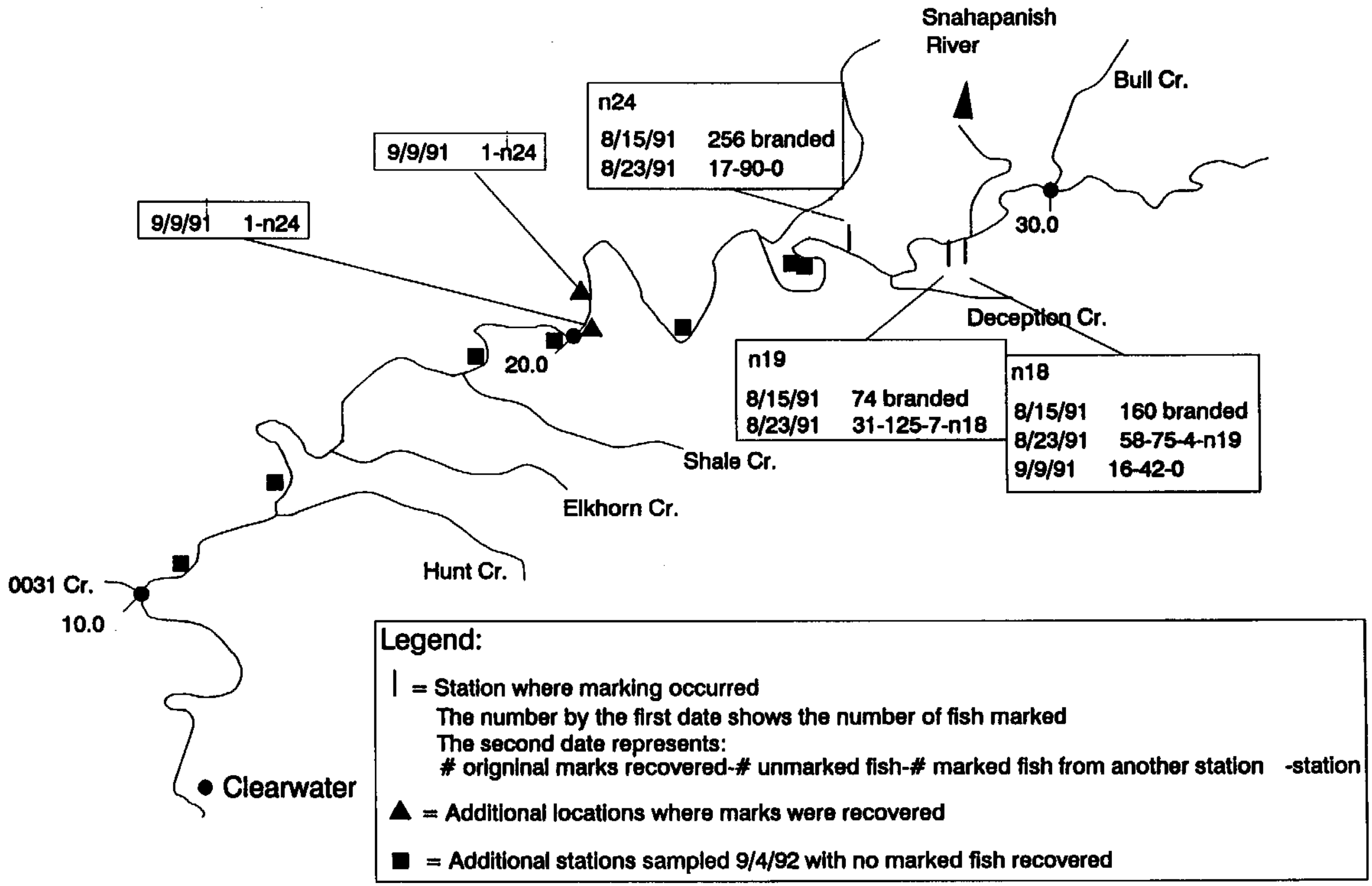

Figure 6. Locations where juvenile coho salmon were marked and recovered in the mainstem Clearwater River during 1991.

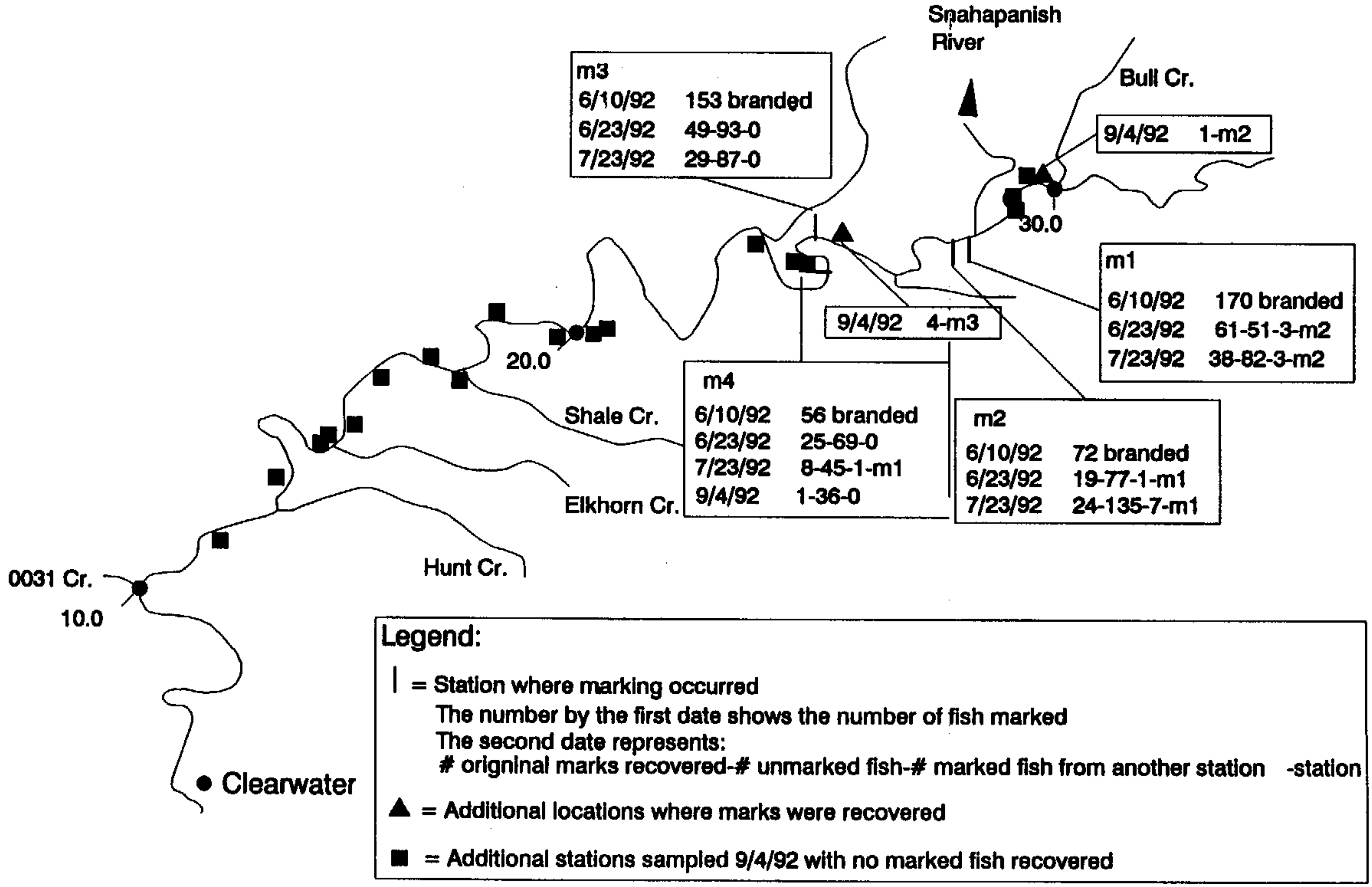

Figure 7. Location where juvenile coho salmon were marked and recovered in the mainstem Clearwater River during 1992.

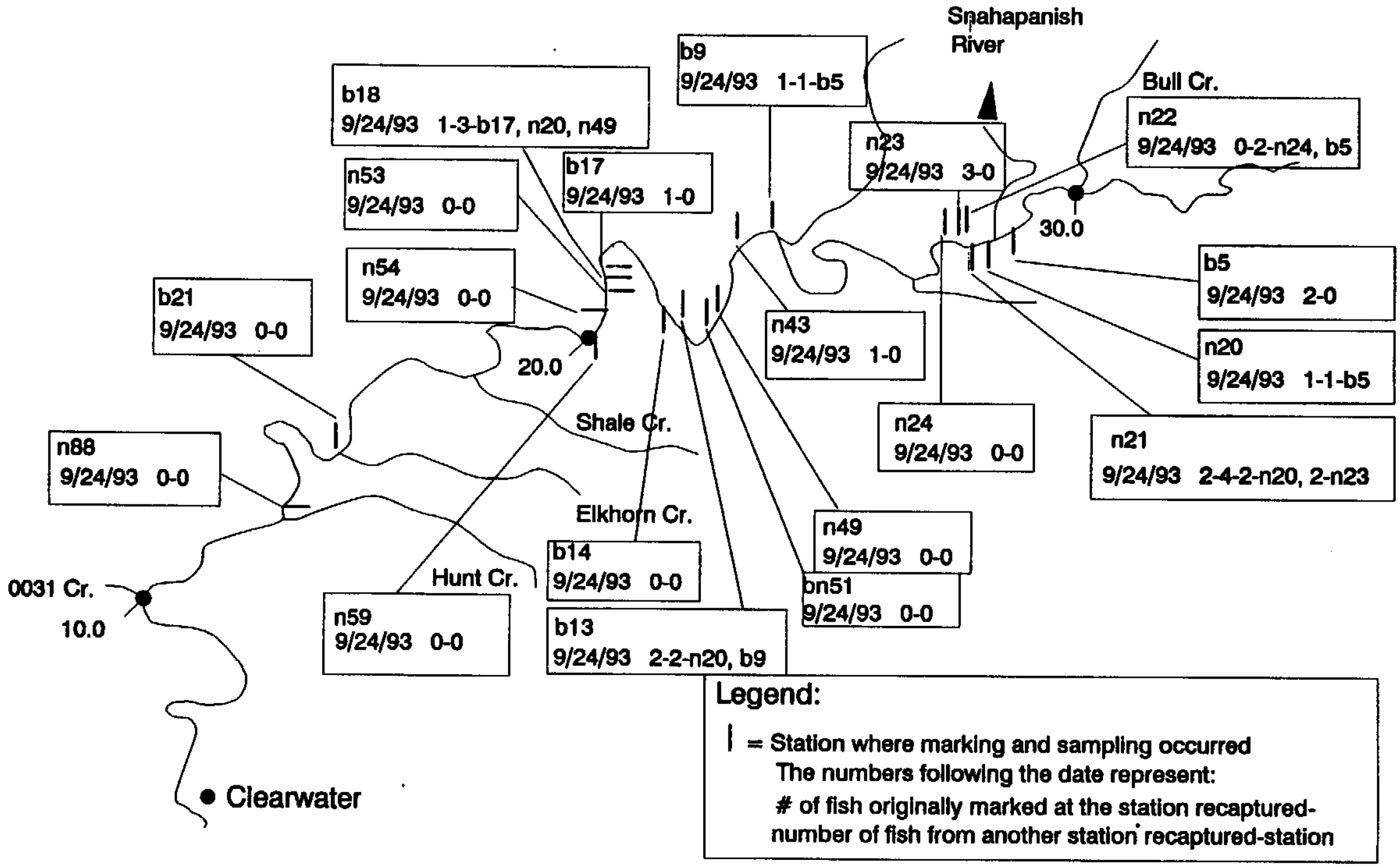

Figure 8. Location where juvenile coho salmon were marked and recovered in the mainstem Clearwater River during 1993.

Effect of Enhancement on Wall-base Channel Immigration

Immigration of coho salmon into wall-base channel ponds varied between years and between ponds (Appendix A). Between 531 and 1939 coho salmon were caught entering each of these ponds during the four years they were sampled. Recoveries of coho salmon marked at individual mainstem woody debris accumulation sites ranged from 0 to 11 individuals per site. Totals of 37, 41, and 23 marked coho salmon were recovered during 1991, 1992, and 1993, respectively. Marked coho salmon generally moved downstream prior to moving into a wall-base channel pond. Of the 101 marked fish recovered, all but one had moved downstream. Marked fish had migrated between 0 and 27.5 km (ave. 9.3) prior to being captured at wall-base channel ponds. The one fish recovered at a pond upstream of the station where it was marked had traveled 7.2 km.

Introducing woody debris bundles into study reaches of the mainstem Clearwater River did not increase the percentage of marked fish recovered (Table 3) or the estimated number (Table 4) of coho salmon moving into wall-base channel ponds. Recovery rates of coho salmon marked at debris accumulations in enhanced and control reaches were not statistically different. Results were the same whether the data from 1992-1993 were combined for analysis (t-test: $P=0.4321$) or when it was analyzed separately (t-test: 1992: $P=0.7107$; 1993: $P=0.2451$; Power < 0.30 all tests) (Table 3). Numbers of coho salmon migrating into wall-base channels appeared to be influenced more by the groups of study reaches than by the introduction of woody debris (Table 4). More coho salmon were estimated to have migrated into wall-base channels from the Bull, Peterson, and Elkhorn reaches than the Deception, Shale, and Hunt reaches, whether they were enhanced by introducing woody debris (1993) or not (1992). In contrast, coho salmon rearing in the Deception, Shale, and Hunt reaches were recovered at higher percentages than those from the Bull, Peterson, and Elkhorn reaches, whether the habitat was enhanced (1992) or not (1993). More coho salmon from the Bull, Peterson, and Elkhorn reaches were estimated to have moved into wall-base channel ponds during both 1992 and 1993 even though the recovery rates were lower (Table 4). This was due to the higher estimated coho salmon populations in these reaches (Table 4).

The percent of coho salmon marked at introduced and natural woody debris accumulation sites recovered immigrating into wall-base channels were not significantly different when the data were combined for analysis (t-test: $P=0.1687$) or when data from 1992 (t-test: $P=0.8800$) and 1993 (t-test: $P=0.6171$) were analyzed separately (Table 5). However, coho salmon marked at natural debris stations were recovered more frequently (t-test: $P=0.0163$) than those marked at introduced debris stations during 1990 (Table 5), although coho salmon were marked at only two natural debris stations compared to 10 introduced debris stations during that year.

The river habitat (pool, riffle, glide) in which coho salmon were marked did not affect the percent recovered at wall-base channel ponds (All years: $P=0.5753$; 1990: $P=0.5926$; 1992: $P=0.6087$; 1993: $P=0.9270$). Although not significant, recovery rates of coho salmon marked at introduced debris accumulations in pools (3.3%) appeared greater than those from introduced debris accumulations located in glides (1.6%). The opposite may have been true for natural debris accumulations, with numerically more coho salmon marked at natural debris accumulations in glides (6.1%) being recovered than that observed in pools (4.7%).

Coho Salmon Size Comparison

No significant differences in coho salmon lengths were observed between enhanced and control reaches during 1992 (t-test: $P=0.1205$) or 1993 (t-test: $P=0.3682$) or between introduced and natural debris stations during 1990 and 1992-1993 (t-test: 1990, $P=0.0568$; 1992, $P=0.2252$; 1993, $P=0.9799$). Coho salmon from pools were significantly (ANOVA: $P=0.0356$) longer than those from glides (Tukey: $P=0.0268$) during 1990 but not 1992 (t-test: $P=0.3582$) or 1993 (t-test: $P=0.8184$) (Figure 9). No significant difference existed in coho salmon length between pool and riffles or glides and riffles for 1990. No riffles were sampled during 1992 or 1993.

There were significant (ANOVA: $P<0.0001$ in all years) differences in the fork length of coho salmon migrating into the wall-base channel ponds sampled during 1990 and 1992-1993 (Figure 10). Juvenile coho salmon migrating into Swamp Creek Beaded Channel were significantly smaller than those migrating into the other ponds during all years. Juvenile coho salmon migrating into Airport and Morrison ponds during 1992 and 1993 were longer than those migrating into any other pond. There was no significant difference in the fork length of juvenile coho salmon migrating into these two ponds. No other significant differences existed.

Table 3. Number of juvenile coho salmon marked in enhanced and control reaches along with the number and percentage of marked fish recovered migrating into wall-base channel ponds.

Treatment	1992			1993			Total		
	Number Marked	Number Recovered	Percent Recovered	Number Marked	Number Recovered	Percent Recovered	Number Marked	Number Recovered	Percent Recovered
Enhanced	293	17	5.8	561	8	1.4	854	25	2.9
Control	327	16	4.9	152	10	6.6	479	26	5.4
Total	620	33	5.3	713	18	2.5	1,333	41	3.1

Table 4. Estimated coho salmon abundance in enhanced and control reaches during August 1992-1993 and the estimated number of these fish migrating into the wall-base channel ponds sampled during this study. The estimated number of fish from enhanced and control reaches migrating into wall-base channel ponds was calculated by multiplying the percent of marks recovered (Table 3) by the estimate of coho salmon abundance in each reach type. The Deception, Shale, and Hunt reaches wee enhanced during 1992 and controls during 1993, while Bull, Peterson, and Elkhorn reaches were controls in 1992 and enhanced in 1993.

Treatment	1992		1993		Total	
	Estimated abundance	Est. no. migrating into ponds	Estimated abundance	Est. no. migrating into ponds	Estimated abundance	Est. no. migrating into ponds
Enhanced	863	50	3,387	53	4,250	106
Control	1,744	85	551	36	2,295	124

Table 5. Number of juvenile coho salmon marked at introduced and natural debris stations along with the number and percentage of marked coho salmon recovered migrating into wall-base channel ponds. Included are the number of stations where marking occurred and the number and percentage of stations from which marks were recovered.

Debris type	1990			1992			1993			Total		
	Number Marked	Number Recovered	Percent Recovered	Number Marked	Number Recovered	Percent Recovered	Number Marked	Number Recovered	Percent Recovered	Number Marked	Number Recovered	Percent Recovered
Number of coho salmon marked and recovered												
Introduced	680	7	1.0	224	14	6.3	515	8	1.6	1,419	29	2.0
Natural	229	14	6.1	396	19	4.8	198	10	5.1	823	43	5.2
Total	909	21	2.3	620	33	5.3	713	18	2.5	2,214	72	3.2
Number of Stations Where Marking occurred and from which recoveries were made												
Introduced	10	6	60.0	7	6	85.7	6	3	50.0	23	15	65.2
Natural	2	2	100.0	11	10	90.9	7	2	28.6	20	14	70.0
Total	12	8	66.7	18	16	88.9	13	5	38.5	43	29	67.4

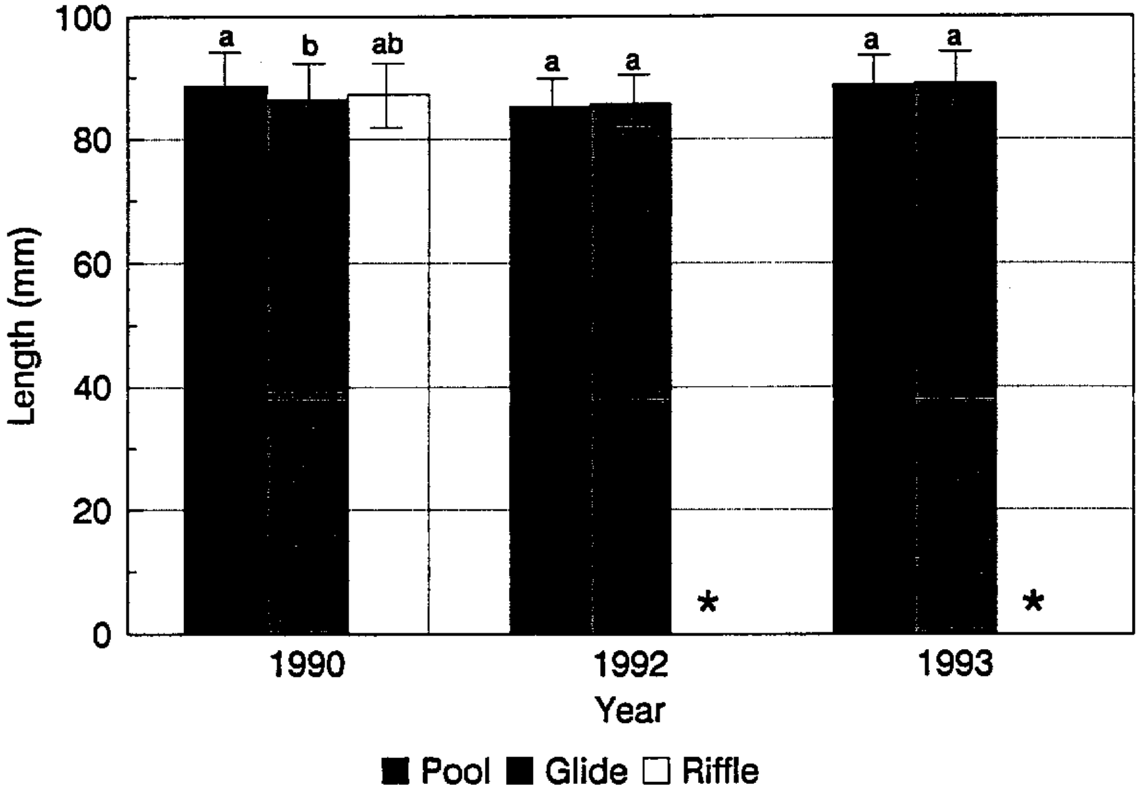

Figure 9. **Mean (+/- 2 SE) fork length of coho salmon from different riverine habitats, 1990, 1992-1993. Groups of bars with different letters are significantly different (ANOVA and Tukey: $P<0.05$). (* = not sampled).**

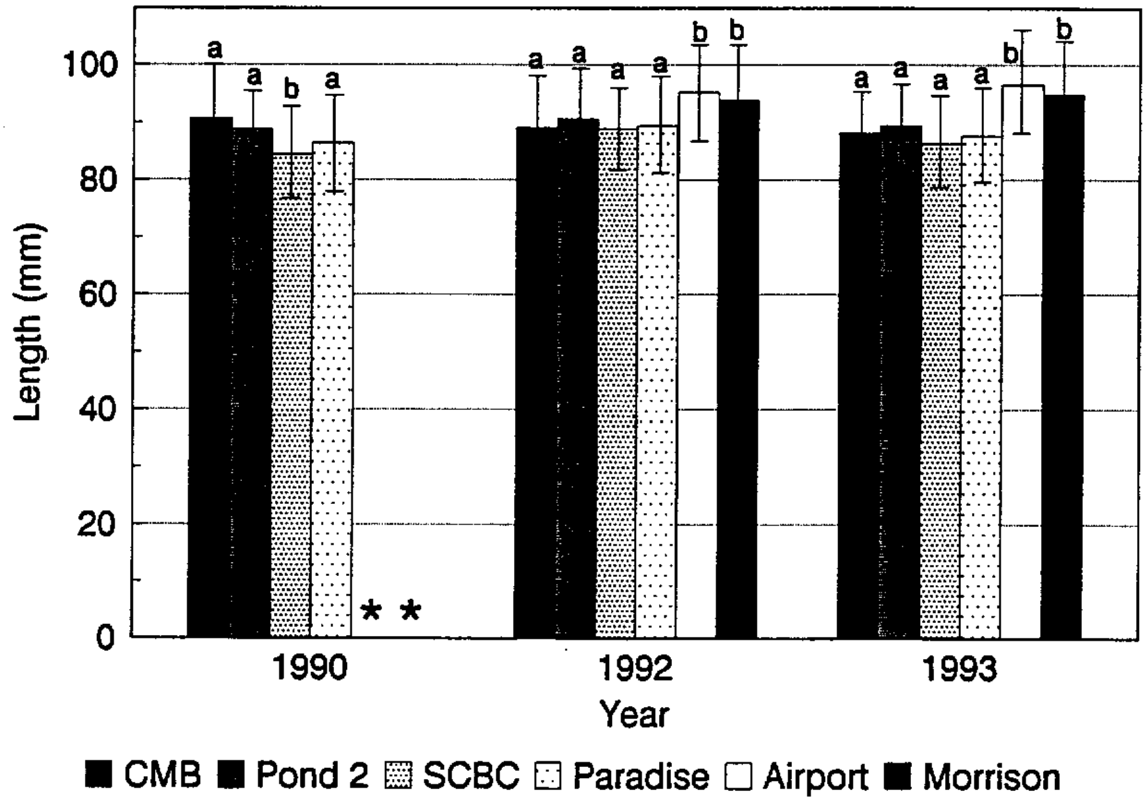

Figure 10. Mean (+/- 2 SE) fork length of coho salmon immigrating into wall-base channels during 1990, 1992-1993. Groups of bars with different letters are significantly different (ANOVA and Tukey: $P<0.05$). (CMB=Coppermine Bottom Pond, SCBC=Swamp Creek Beaded Channel, *=not sampled).

DISCUSSION

Introducing woody debris bundles into the mainstem Clearwater River increased coho salmon summer rearing densities (fish/km). Coho salmon summer rearing densities were positively related to woody debris densities (no. pieces of wood/km). The percent of coho salmon marked during late summer in mainstem study reaches and later recovered migrating into wall-base channel ponds during the fall was not increased by introducing woody debris bundles. Recovery of coho salmon marked in the mainstem appeared to be influenced more by the groups of study reaches receiving different treatments than by introductions of woody debris. Although summer rearing densities were increased in enhanced reaches, estimated numbers of coho salmon moving into wall-base channel ponds during the fall were not increased in enhanced reaches.

Woody debris introductions appear to be a useful technique for increasing coho salmon summer rearing densities in the mainstem Clearwater River. Summer rearing densities were higher in reaches enhanced by introducing woody debris bundles than control reaches and were positively influenced by increasing woody debris densities. Results of this study support the premise that habitat restoration in large mainstem rivers may increase salmonid production of these systems (Sedell and Luchessa 1982). Although summer populations of salmon and trout have been increased through woody debris introductions, most examples come from relatively small streams (Ward and Slaney 1981; Anderson 1982; House and Boehne 1985, 1986; Nickelson et al. 1992b). This is also true for examples of increasing salmonid rearing densities with increasing densities of woody debris (e.g. House and Boehne 1986; McMahon and Holtby 1992). Results reported in this study support conclusions of related studies which determined that the presence of woody debris was a primary factor determining coho salmon distribution in this river and that abundance was influenced by the size and density of woody debris accumulations (Peters 1996).

Although results presented in this study demonstrate that summer rearing densities may be increased through woody debris introductions, it did not address question of whether stable woody debris which could withstand winter flows could be introduced into this relatively large channel. The woody debris bundles introduced in this study were meant to be temporary which allowed the treatments of the reaches to be switched each year. Therefore, the fact that many of the introduced woody debris structures were washed out during the August 1991 flood (and winter floods of 1992 and 1993) should not be misconstrued to mean that stable woody debris cannot be introduced into this system. The persistence of most natural woody debris accumulations sampled during this study (1990-1993) suggests that stable woody debris could be introduced to this system. However, these introductions would likely be limited to pool habitats and to locations on the point bar side of glide habitats just downstream of river bends. Although this eliminates a number of the locations where woody debris bundles were introduced in the present study, it also focuses woody debris introductions on the areas with the greatest potential benefits to coho salmon rearing habitat. Coho salmon abundance was greatest at large, dense debris accumulations located in pools (Peters 1996).

A second question is whether the cost of introducing woody debris into mainstem rivers is justifiable. The Clearwater River has approximately 56.6 km of mainstem habitat available for anadromous salmonids (Phinney and Bucknell 1975). By extrapolating average annual observed coho salmon rearing densities in control and enhanced reaches (Table 6), it appears that enhancement could result in a 48-158% increase in the number of coho salmon rearing in this habitat. This extrapolation assumes that enhancement would have similar effects throughout the entire mainstem river and that food does not limit production. Based on the large size of coho salmon observed in the mainstem (80-90 mm) compared to those in tributaries of the mainstem (70-80 mm, Peters, unpublished data), the assumption that food does not limit production in the mainstem seems accurate. These extrapolations were calculated by summing corrected snorkel estimates of coho salmon abundance at all stations snorkeled for each study reach. We corrected the snorkel estimates because salmonid abundance estimates using snorkeling techniques have been found to underestimate actual abundance (Slaney and Martin 1987). Snorkel estimates in the present study were found to represent approximately 67% of the actual population (Appendix B). Corrected snorkel estimates were calculated by applying the regression equation developed in Figure B.1 (Appendix B) to snorkel estimates for each woody debris accumulation where snorkel estimates were completed.

Table 6. Corrected annual estimates of juvenile coho salmon densities (coho/km) observed in enhanced and control reaches and extrapolated population estimate for the entire mainstem.

	Coho salmon density (coho/km)		Estimated population entire mainstem	
Date	Control	Enhanced	Control	Enhanced
June 1991/1992	332.0	678.1	18,791	38,380
June 1992/1993	288.8	426.5	16,346	24,140
August 1992/1993	197.0	507.7	11,150	28,736

Results of this study (i.e., comparing fish counts in different study reaches) would be seriously compromised if significant redistribution of juvenile coho salmon occurred during the summer. Movement of juvenile coho salmon in the mainstem Clearwater River was minimal during this study.

Most fish moved relatively short distances ($\approx$100 m) and remained in the same study reach, although some fish moved up to 9 km downstream from where they were originally marked. Marked fish recaptured in study reaches other than those where they were marked were generally recaptured in mid- to late-September. We suspect, based on movements of fish marked in mid- to late-September for monitoring wall-base channel immigration, that coho salmon in the mainstem Clearwater River initiate downstream migrations in search of overwintering habitats in September prior to the first fall freshet. The observation of little movement between study reaches and the fact that our late summer populations surveys were normally completed in mid-August suggest that the data presented was not biased by fish redistribution.

Although enhancement apparently increased mainstem juvenile coho salmon densities, it did not increase the number of coho salmon migrating into wall-base channel ponds. Recovery rates from control reaches and natural debris stations were nearly twice those of enhanced reaches and introduced debris accumulations. Although these differences were not statistically significant, the power of the statistical test was less than 0.30. Thus, the difference in my opinion should be considered biologically meaningful. The apparent better contribution to wall-base channel immigration from control than from enhanced reaches may be an artifact of the apparently poor contribution of coho salmon from introduced versus natural debris stations. Most coho salmon marked in enhanced reaches were marked at introduced debris accumulations, while all fish marked in control reaches were at natural debris accumulations. Thus, observed differences between introduced and natural debris accumulations would be reflected in the comparison of enhanced and control reaches.

The introduced debris accumulations used in this study may have provided poorer quality habitat during high flows associated with fall freshets. Introduced woody debris accumulations were constructed using relatively small trees and lashed to existing debris using rope so they would wash out during winter flows to allow the treatments in different reaches to be switched each year. McMahon and Hartman (1989) found that juvenile coho salmon remained near debris during daylight and migrated at night during simulated freshets in an outdoor stream channel. The introduced woody debris bundles used in this study may not have afforded fish this option. Instead of migrating at night, which may afford protection from predators (Mace 1983; Wood et al. 1993), juvenile coho salmon residing at introduced debris stations may have had to migrate whenever the station failed. This may have resulted in increased mortality of coho salmon rearing at introduced debris accumulations during downstream migration. If so, enhancement with larger, more stable debris may increase the number of coho salmon moving into wall-base channels from enhancement sites.

When corrected snorkel estimates (as described above) as coho salmon abundance at natural and introduced woody debris accumulations (Table 7) were used to calculate immigration of coho salmon from woody debris accumulations in the mainstem, it was estimated that 23-55 coho salmon from introduced woody debris accumulations could have immigrated into wall-base channel ponds during 1990-1993 (Table 7). In contrast, coho salmon residing at natural woody debris accumulations during the summer were estimated to have contributed between 104 and 195 immigrants during this same period (Table 7). These calculations are based on the four (1990) to six (1992 and 1993) wall-base channel ponds monitored during this study. It is likely that coho salmon using introduced debris bundles moved into other wall-base channel ponds downstream from our enhanced reaches. The Washington Department of Fish and wildlife (WDFW) has described more than 30 such habitats in the Clearwater River Basin (Dave King, WDFW, personal communication). Thus, our estimates take into account only 20% of available wall-base channel ponds. By extrapolating contribution rates to account for additional wall-base channel ponds, estimated contribution of coho salmon using introduced debris bundles to wall-base channel immigration would be approximately: 1990, 115; 1992, 275; and 1993, 200. This assumes that immigration rates are equal, which may not be the case. Nevertheless, mainstem habitat enhancement would have limited benefits to overall wall-base channel immigration. However, only a small portion of the mainstem was enhanced during this study (1990--14 km; 1992 & 1993--8.9 km), with un-enhanced reaches interspersed between the enhanced reaches. Enhancement of the entire mainstem should result in greater migration rates of coho salmon into wall-base channel ponds than were reported here.

The effectiveness of future enhancement activities in the mainstem Clearwater River could be increased with a better understanding of factors causing the initiation of fall migration of juvenile coho salmon to overwintering habitats. Peterson (1982b) observed peak migration of coho salmon into wall-base channel ponds during freshets, with the greatest immigration rates occurring during the first few fall freshets. Sampling in the mainstem following marking showed that some coho salmon were moving downstream prior to the first freshets, suggesting that fall migration is initiated prior to the first fall freshet. This could result in individuals migrating into free-running tributaries prior to the first freshet because wall-base channel ponds are generally inaccessible until the first major freshet. These fish could also continue migrating downstream where they use lower river wall-base channel ponds potentially affecting observed coho salmon migration rates into wall-base channel ponds. One would expect greater percentages of coho salmon to migrate into wall-base channel ponds during years with early fall freshets as compared to years with relatively dry falls. Therefore, modification of wall-base channel accessibility may have a greater effect on coho salmon immigration rates into wall-base channel ponds than introducing woody debris to the mainstem, especially during dry falls. However, the early initiation of coho salmon migration could also result in poorer survival of coho salmon in areas where woody debris accumulations are sparse because migrating salmon may not find adequate woody debris accumulations as they begin their migration. Thus, contribution rates reported here may have been higher if the entire mainstem had been enhanced.

The addition of woody debris may be an effective habitat enhancement method for increasing coho salmon summer rearing densities in the mainstem Clearwater River. However, this enhancement may have only limited effects on the fall migration rate of coho salmon into wall-base channel ponds. It is possible that larger, more stable debris, which is less likely to wash away, and affords fish more velocity refuge during high flows, or modification of wall-base channel pond outlets to make them more accessible during the fall could increase immigration into wall-base channel ponds. The synergy of these two techniques could improve coho salmon production in this river system. However, more information is needed regarding the initiation of coho salmon fall migration to wall-base channel ponds.

Table 7. Estimated numbers of coho salmon using introduced and natural woody debris stations during August 1990, 1992, and 1993 and their estimated contribution to wall-base channel immigration. Estimates are based on corrected estimates from the regression in appendix B.

Year	Estimated coho salmon abundance		Estimated coho salmon immigrants	
	Introduced	Natural	Introduced	Natural
1990[a]	2,232	1,709	23	104
1992	884	2,686	55	129
1993	2,569	3,860	40	195

[a]Recoveries from only 4 ponds

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APPENDIX A: Pond trapping data

Table A.1. Total coho salmon caught migrating into four wall-base channels of the Clearwater River, and the number of branded fish recovered during the fall of 1990.

Pond	Number Trapped	Brands
Coppermine Bottom	1,428	7
Pond 2	531	4
Swamp Creek	1,479	2
Paradise Pond	1,835	8
Total	5,002	21

Table A.2. Total coho salmon caught migrating into six wall-base channels of the Clearwater River, and the number of branded fish recovered during 1991.

Pond	Wild		Hatchery	
	Number Trapped	Brands	Number Trapped	Brands
Coppermine Bottom	1,007	4	17	0
Pond 2	796	7	8	1
Swamp Creek	913	6	35	0
Paradise	1,591	9	48	1
Airport	1,586	8	21	0
Morrison	1,115	3	22	0
Total	7,008	37	151	2

Table A.3. Total coho salmon caught migrating into six wall-base channels of the Clearwater River, and the number of branded fish recovered during the fall of 1992.

Pond	Wild		Hatchery	
	Number Trapped	Brands	Number Trapped	Brands
Coppermine Bottom	643	1	4	0
Pond 2	1,380	5	6	0
Swamp Creek	686	6	2	0
Paradise	972	10	3	1
Airport	1,012	8	6	0
Morrison	1,939	11	14	0
Total	6,632	41	35	1

Table A.4. Total coho salmon caught migrating into six wall-base channels of the Clearwater River, and the number of branded fish recovered during the fall of 1993.

Pond	Number Trapped	Brands
Coppermine Bottom	1,273	4
Pond 2	1,082	4
Swamp Creek	817	1
Paradise	875	2
Airport	668	5
Morrison	850	7
Total	5,565	23

APPENDIX B: Comparison of snorkel estimates to catch estimates using beach seining.

During the summer of 1994 we checked the accuracy of our snorkel estimates by comparing them to estimates made using a modified removal method (catch estimate). Only seven stations were used for this comparison due to time constraints. Following the initial snorkel estimate, a beach seine was used to capture as many fish as possible from the station. The fish were counted and stored in live net tanks. Once the water cleared, a second snorkel estimate was made, again followed by an attempt to capture fish with the beach seine. A final snorkel estimate was made once the water cleared.

The population estimate for the 'catch' method was conservatively calculated by adding the number of fish caught by the two seining efforts and the final snorkel estimate (Table B.1). The relationship between the initial snorkel estimates (dependent variable) and removal estimates (independent variable) was evaluated with linear regression model (Figure B.1).

Table B.1. Estimated juvenile coho salmon abundance estimates at seven debris stations using snorkel and 'catch' estimates.

Date	Station	Snorkel Estimate #1	Snorkel Estimate #2	Snorkel Estimate #3	Seine Estimate #1	Seine Estimate #2	Catch Estimate
8/10/94	B7&8	150	60	25	121	49	195
8/10/94	B13	20	18	6	9	22	37
8/10/94	B28	125	25	23	135	11	169
8/11/94	B29	185	95	36	135	102	273
8/11/94	B30	175	115	75	149	79	303
8/11/94	D1	25	15	8	19	9	36
8/11/94	D2	90	25	4	85	33	122

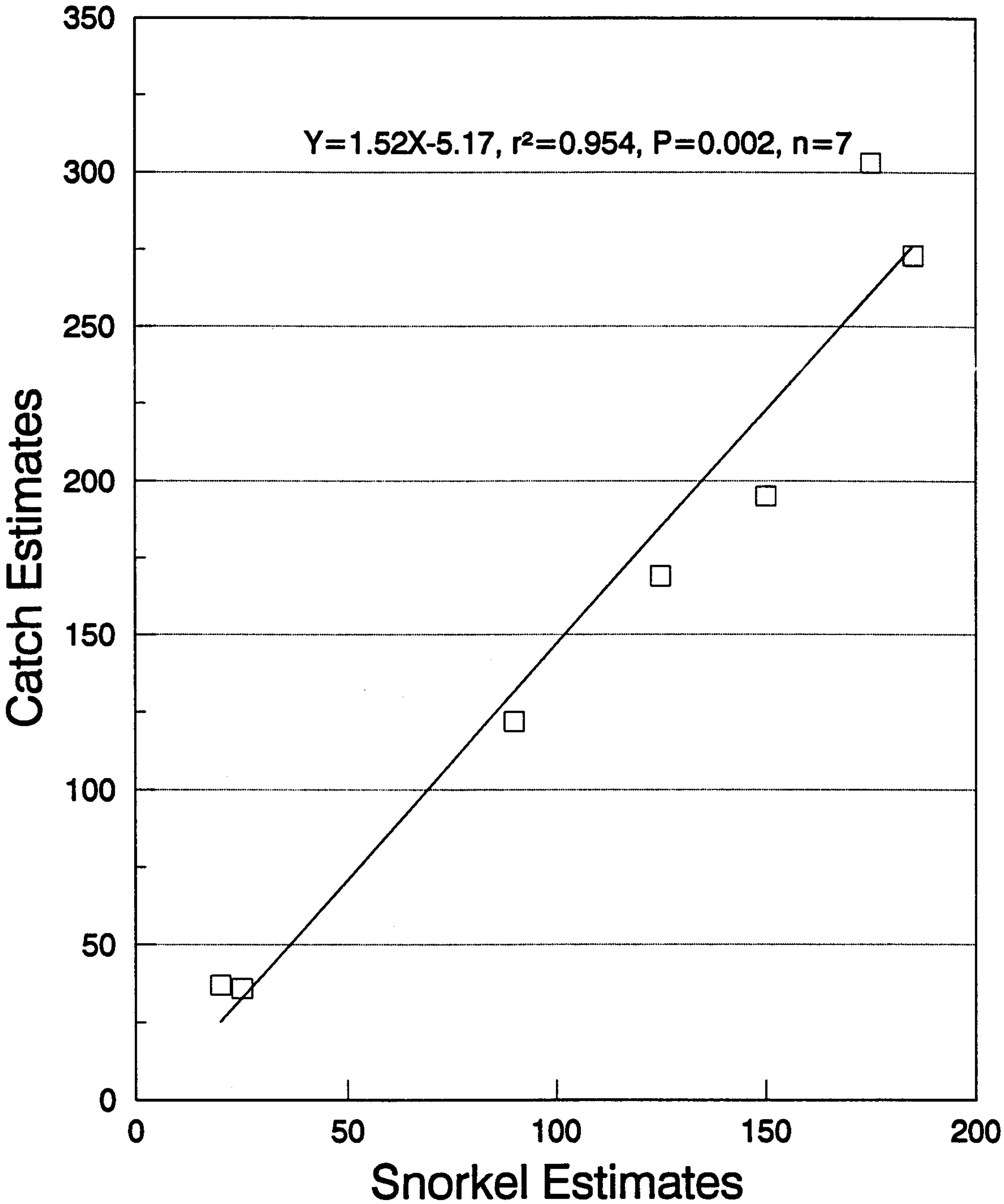

Figure B.1. **Results of snorkel estimate and 'catch' estimate regression.**